Practical implementation of the Wave Analog of Common Depth Point Method

Andrey N. Kremlev, Russian Academy of Sciences, Novosibirsk, Russia,
Viatcheslav I. Priimenko, Sérgio A.M. Oliveira and Roseane M. Misságia,
Lenep/Uenf, Macaé, Brazil

Abstract

Development and application of the inverse scattering problems of acoustic and seismic waves for seismic data processing and investigation of sedimentary cover is an actual and perspective tendency. In this report we describe practical realization of the Wave Analog of Common Depth Point Method (WCDP) for 2D seismic data processing and represent its testing on synthetic data corresponded to typical geological objects: dipping reflectors, diffraction points and salt dome tectonic model.

Introduction

The WCDP method is a method for multi channel seismic data processing. Among migration methods on unstacked data the WCDP method stands out by the fact that it is based on the strict solution (in linear approximation) of inverse acoustic scattering problem using overdetermined multifold data, A.N.Kremlev (1979, 1985). This problem consists for 2D case in reconstruction of function $a(\vec{\rho})$ describing medium inhomogeneities by wave field $u(x, x_0, t)$ registered for different source (x_0) and receiver (x) positions on free surface. This wave field satisfies to the following Cauchy problem, Bleisten (1979):

$$\frac{\partial^2 u}{\partial t^2} = c^2(1 + a(\vec{\rho}))\nabla^2 u + \delta(t)\delta(\vec{\rho} - \vec{\rho_0}), \qquad (1)$$

$$u|_{t<0} \equiv 0,$$

where c is the velocity of acoustic waves in background medium and $(\vec{\rho}, \vec{\rho_0}, t) \in R^2 \times R^2 \times R, \vec{\rho} = (x, z)$, $\vec{\rho}_0 = (x_0, z_0)$. The result of the inverse scattering problem solution for Cauchy problem (1) is linear focusing operator:

$$\alpha(\vec{\rho}) = \int \frac{d\omega}{2\pi}\frac{d\chi}{2\pi}\frac{d\chi_0}{2\pi}\Phi_v(\vec{\rho}, \chi, \chi_0, \omega)\hat{u}(\chi, \chi_0, \omega), \qquad (2)$$

which allows to calculate vizualization function $\alpha(\vec{\rho})$ averaged over domain with size determined by the signal wave length. In formula (2) function $\hat{u}(\chi, \chi_0, \omega)$ is the spectrum of observed field,

$$\Phi_v(\vec{\rho}, \chi, \chi_0, \omega) = \Theta(\frac{\omega^2}{v^2} - \chi^2)\Theta(\frac{\omega^2}{v^2} - \chi_0^2) \qquad (3)$$
$$\frac{v}{\omega} \cdot \sqrt{\frac{\omega^2}{v^2} + \chi\chi_0 + \sqrt{\frac{\omega^2}{v^2} - \chi^2} \cdot \sqrt{\frac{\omega^2}{v^2} - \chi_0^2}}$$
$$\cdot exp\{i(\chi + \chi_0)x - iz(\sqrt{\frac{\omega^2}{v^2} - \chi^2} + \sqrt{\frac{\omega^2}{v^2} - \chi_0^2})\}$$

is the kernel of focusing operator. Here $\Theta(\cdot)$ is Heaviside's function and v is apriory input wave velocity. Exponential factor in formulae (3) describes phase shift migration of source and receiver coordinates analogously to Gazdag (1978) and Stolt (1978) migration, but proceedings multipliers are the result of strict inverse problems solution. It is necessary to note that stacking formula (2) uses input data overdetermination completely, like the CDP method, and realizes useful signal accumulation. It increases signal/noise ratio in obtained stack and can be used for velocity analysis too.

Practical implementation of the WCDP method

For practical realization of the WCDP algorithm we use transform in (2) from the coordinates "source-receiver" to the coordinates "common midle point- offset" by the formulae:

$$m = (x + x_0)/2, \quad l = x - x_0. \qquad (4)$$

In (x, x_0) coordinates aperture used for approximates calculation of the vizualiztion function $\alpha(\vec{\rho})$ is square ABCD situated on general seismic plane, (see Fig. 1), with diagonal AC oriented along CMP m-axes. In this case of increasing of investigion depth and inclination angles of reflected boundaries it is necessary to increase summation base, too: $AC \to AC_2$. As it seen from Fig. 1, the number of seismic traces involved simuleneously in data processing increases quadratically. Furthermore, domais (as triangles BIB_2K and DLD_2) appear which don't have real seismic data and which we need to fill by zero's traces for FFT implementation. This step has artificial character and does not increase infomativity of profile. In (m,l) coordinate aperture A'B'C'D' is rectangle one and volume of calculation increases linearly under increasing of summation base. Taking into account (4) and making the change

$$q = v(\sqrt{\frac{\omega^2}{v^2} - \chi^2} + \sqrt{\frac{\omega^2}{v^2} - \chi_0^2})$$

we obtain final stacking formula

$$\alpha_v(m,t) = \int_{-\infty}^{\infty} \frac{dq}{2\pi} e^{-iqt} \int_{-\infty}^{\infty} \frac{d\mu}{2\pi} e^{i\mu m} \quad (5)$$
$$\int_{-\infty}^{\infty} \frac{d\nu}{2\pi} \hat{\Phi}_v(m,t,\mu,\nu,q) U(\mu,\nu,q),$$

where integrals with respect to variables q and μ are Fourier integrals which can be calculated by FFT algorithm. Here $\hat{\Phi}_v(\cdot)$ and $U(\cdot)$ are the kernel of focusing operator and the wave field spectrum in new coordinates, correspondengly. Outline, also, that computations in stacking formula (5) for finite aperture increase linearly with stacking base increasing with constant offset range. It is very important for reconstruction of inclined deep reflectors.

Reconstruction of typical geological objects

Fig.2 shows the result of pointwise reflectors reconstruction disposed on different depth and different parts of summation base. We can see good quality of such subjects reconstruction and, it's worth to note, the precise of diffractors reconstruction is closed to its theoretical wave length limit. Figs.3 and 4 show the results of dipping reflectors reconstruction in the case when (a) background velocity used in the inversion, coincides with the real wave velocity c of the medium and for the case when (b) these velocities differ one from another on 25%. Note that for the case (b) inclined reflectors are reconstructed stably inspite of big velocity difference, though they move a little from their real positions.

Salt dome structure reconstruction

A model of salt-diaper structure is shown on Fig.5.That model is highly representative for Campos Basin (Atlantic Ocean, Campos Offshore Deep Water). The synthetic data were calculated by numerical solution of the acoustic wave equation using finite-diffrence approach, acording to algoritm proposed by Oliveira (1999), which considered both variations in velocity and density of medium. The data consists of 521 shot gathers spaced by 30m for 96 receivers spaced with same distance. Fig.6 and Fig.7 show the results of the model reconstruction with background velocity 1500m/s and 1600m/s. All reflectors, including dipping reflectors and undersalt interface are good rebuild though the last one move away from their real positions due to strong lateral velocity variations. We can see some noise in the data due the presence of multiples, spetially the water botton multiple. This indicate the necessity of demultipling the data previous to WCDP processing. Finally, it is important to mention that the CPU time required by WCDP is comparable to the Stolt prestack algorithm.

Acnowledgements

We would like to thank CENPES-PETROBRAS for permission to use the synthetic model with salt dome structure. We are grateful to Prof. Djalma S. Filho for useful discussions during the course of this work supported by FINEP-CTPETRO, grant n.0810/00.

References

A.N.Kremlev, 1979, Technical Report of Computing Center of Siberian Branch of Russian Academy of Sciences: Novosibirsk, Russia.

A.N.Kremlev, 1985, Wave Analogue of the Common Depth Point Method: Geologia i Geofizika, **26**, no. 10, 77–86.

BleistenN., C. J., 1979, Velocity Inversion Procedure for Acustic Waves: Geophysics, **44**, 1077–1087.

Gazdag, I., 1978, Wave Equation Migration with the Phase Method: Geophysics, **46**, 1342–1351.

Oliveira, S. A. M., 1999, Um Algoritmo Prático de Modelagem 3D baseado na Solução da Equação Acústica completa da Onda: Abstract Expanded, 6th International Congress of SBGF.

Stolt, R. H., 1978, Migration by Fourier Transform: Geophysics, **43**, 23–48.

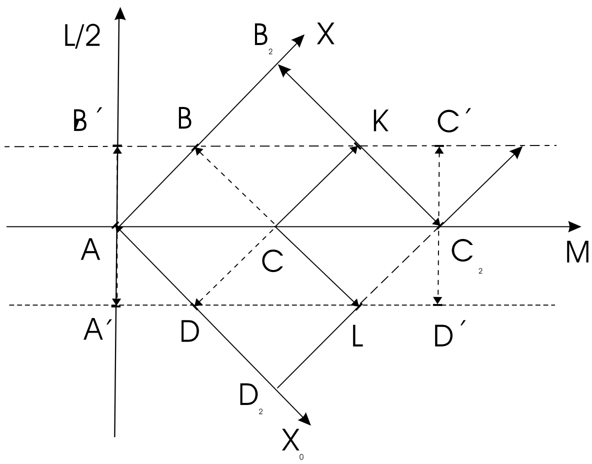

Figure 1: WCDP aperture on general seismic plane

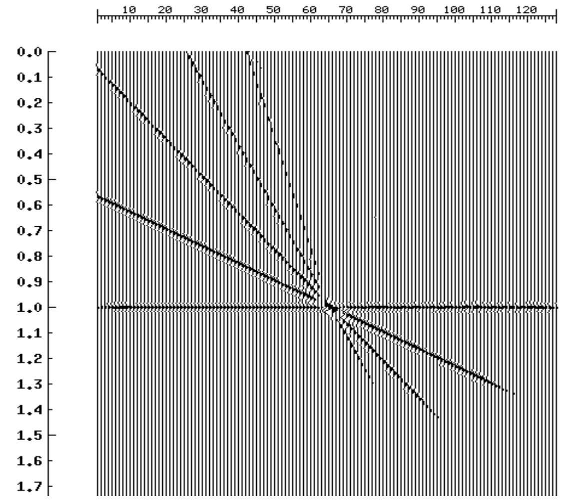

Figure 3: Reconstruction of deep oriented planes. Angles 0,15,30,45 and 60 degries. $V_{media} = V_{input} = 2000m/s$

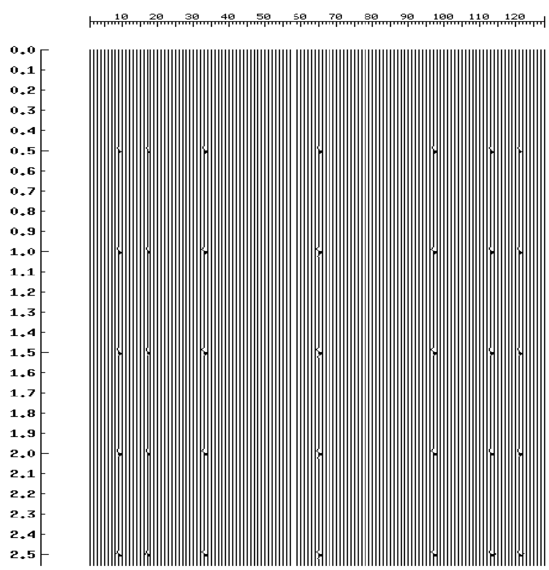

Figure 2: Reconstruction of point difractors.

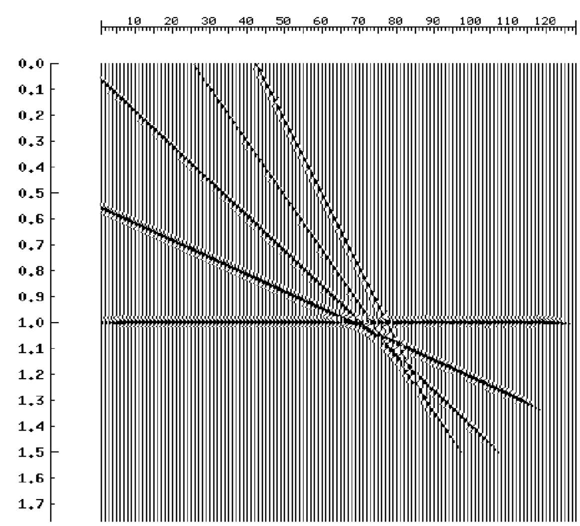

Figure 4: Reconstruction of dipped planes. Angles 0,15,30,45 and 60 degries. $V_{media} = 2000m/s$, $V_{input} = 1500m/s$

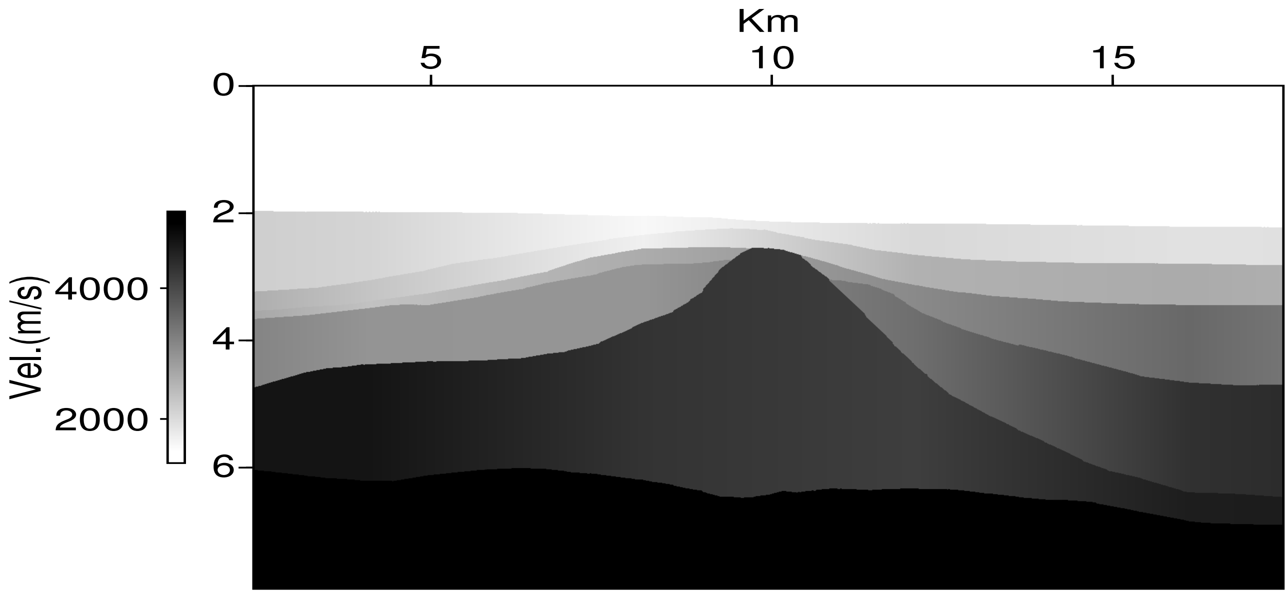

Figure 5: A model of salt-diaper structure.

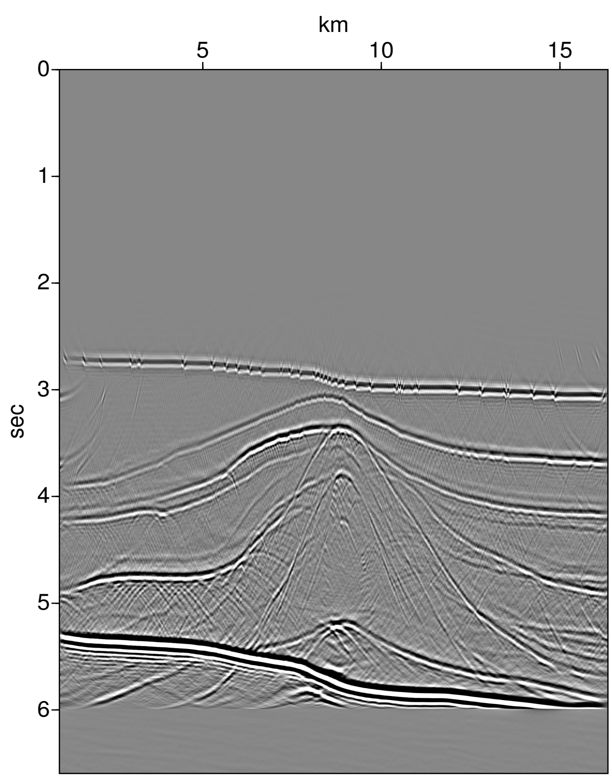

Figure 6: WCDP result, $V_{input} = 1500m/s$.

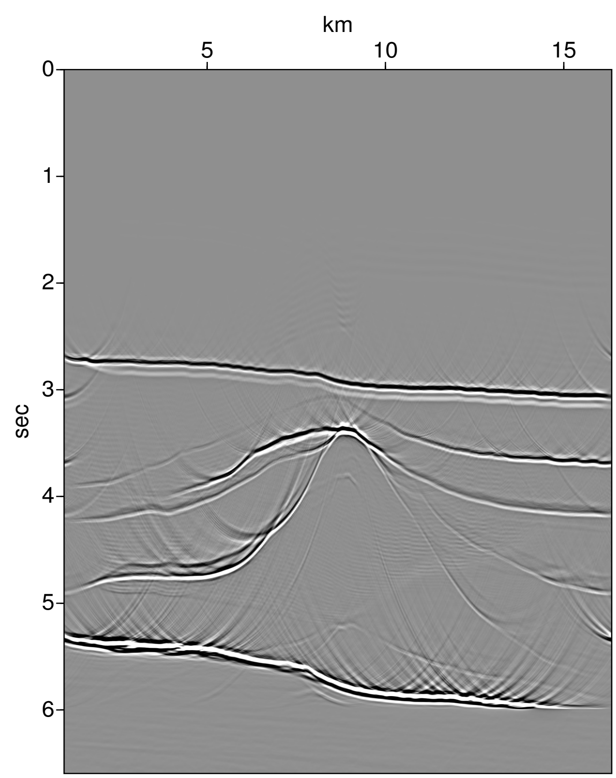

Figure 7: WCDP result, $V_{input} = 1600m/s$.